AePW-3 High Angle Working Group
Test Case Selection and Data Submission

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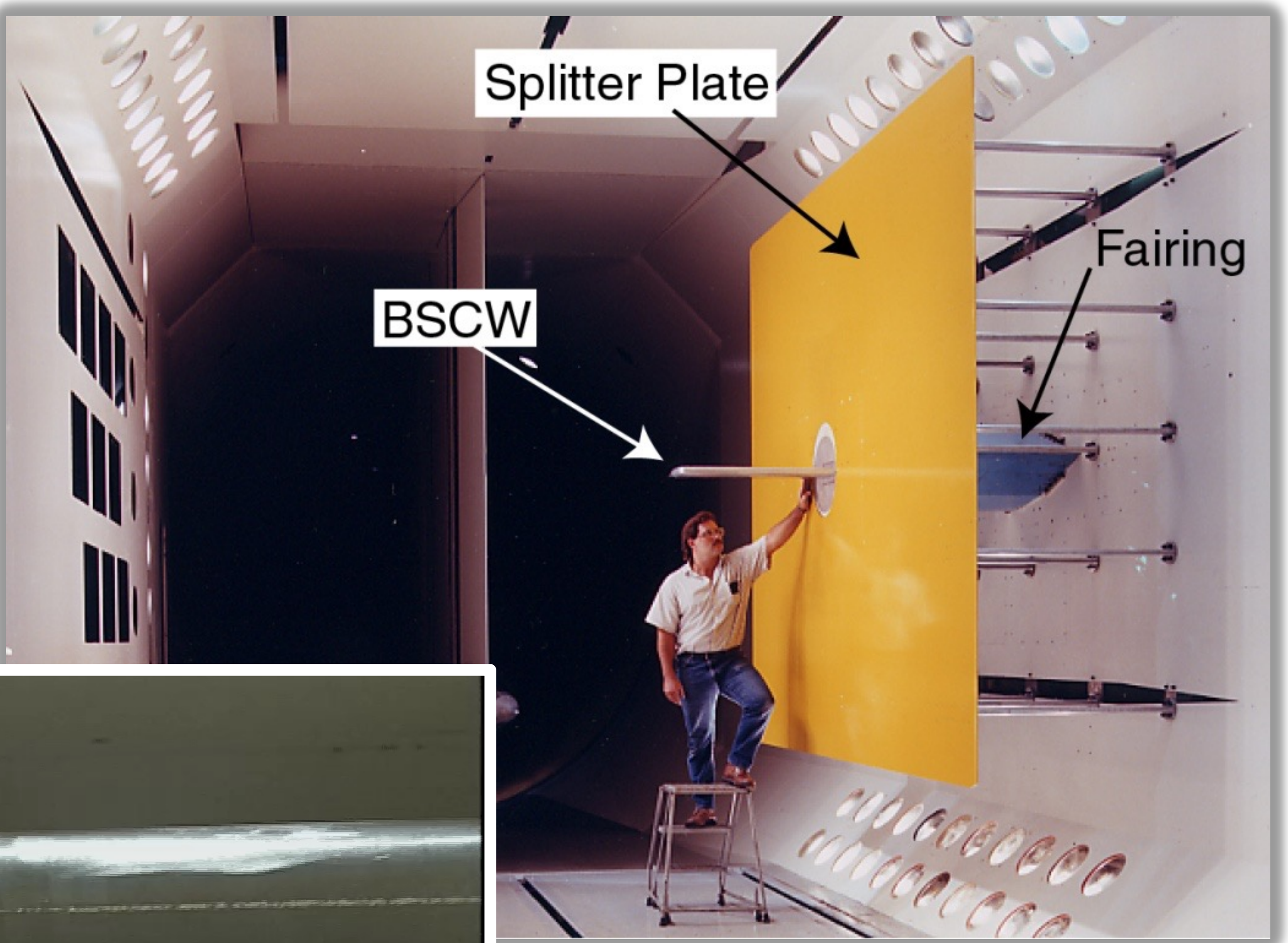
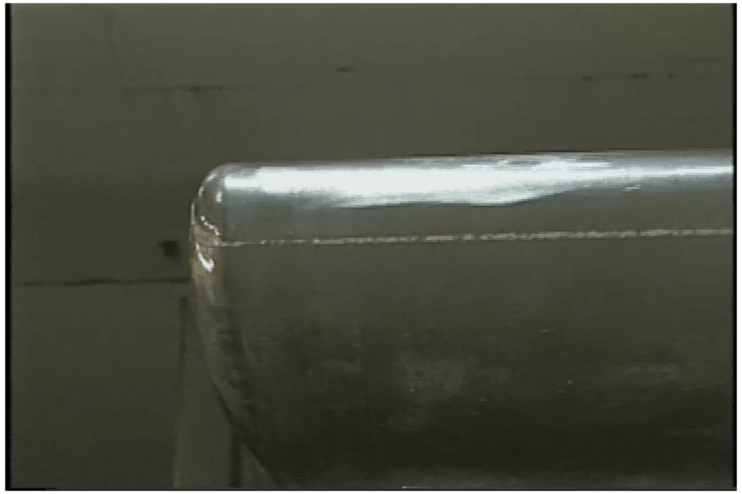
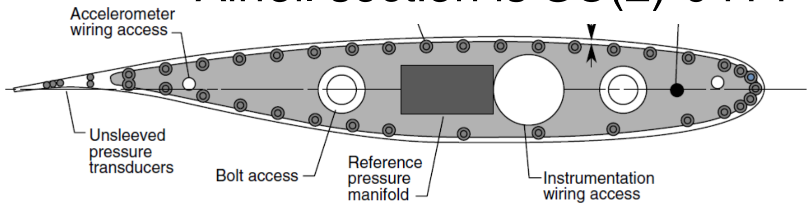
https://nescacademy.nasa.gov/workshops/AePW3/public

AePW-1, AePW-2 Configuration and AePW-3 Configuration for High Angle Working Group: BSCW

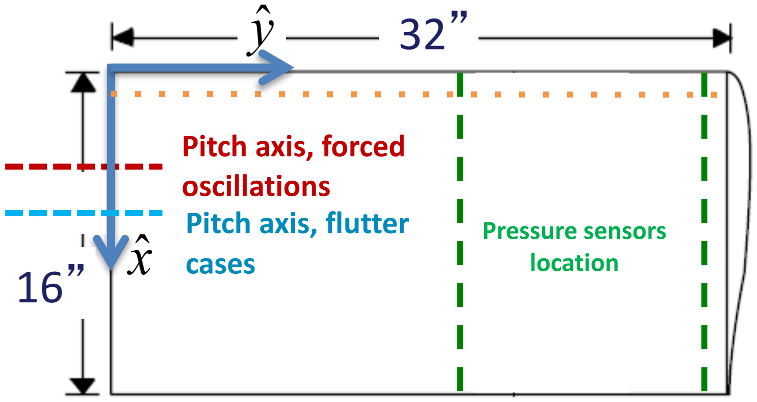




Airfoil section is SC(2)-0414



Cross-section at 60% span, showing the layout of the unsteady pressures.

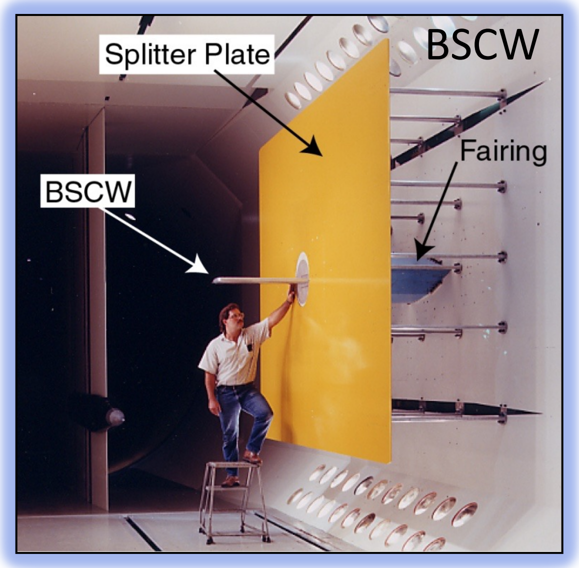


Model planform. Dimensions are in inches.

OTT: Oscillating Turn Table (tested in 2001)

PAPA: Pitch And Plunge Apparatus (tested in 1991)

BSCW – AePW Building Block Approach



- AePW-1: Forced Oscillation in Pitch, Mach 0.85 ✓
- AePW-2:
  - Forced Oscillation in Pitch, Mach 0.7 ✓
  - Flutter, Mach 0.74, 0° ✓
  - Unforced Unsteady, Forced Oscillation, Flutter, Mach 0.85, 5° ✓ ✓
- AePW-3: Flutter, Mach 0.80, 5°

AePW-1 Lessons Learned:
ref. IFASD-2013-1A Heeg et al.

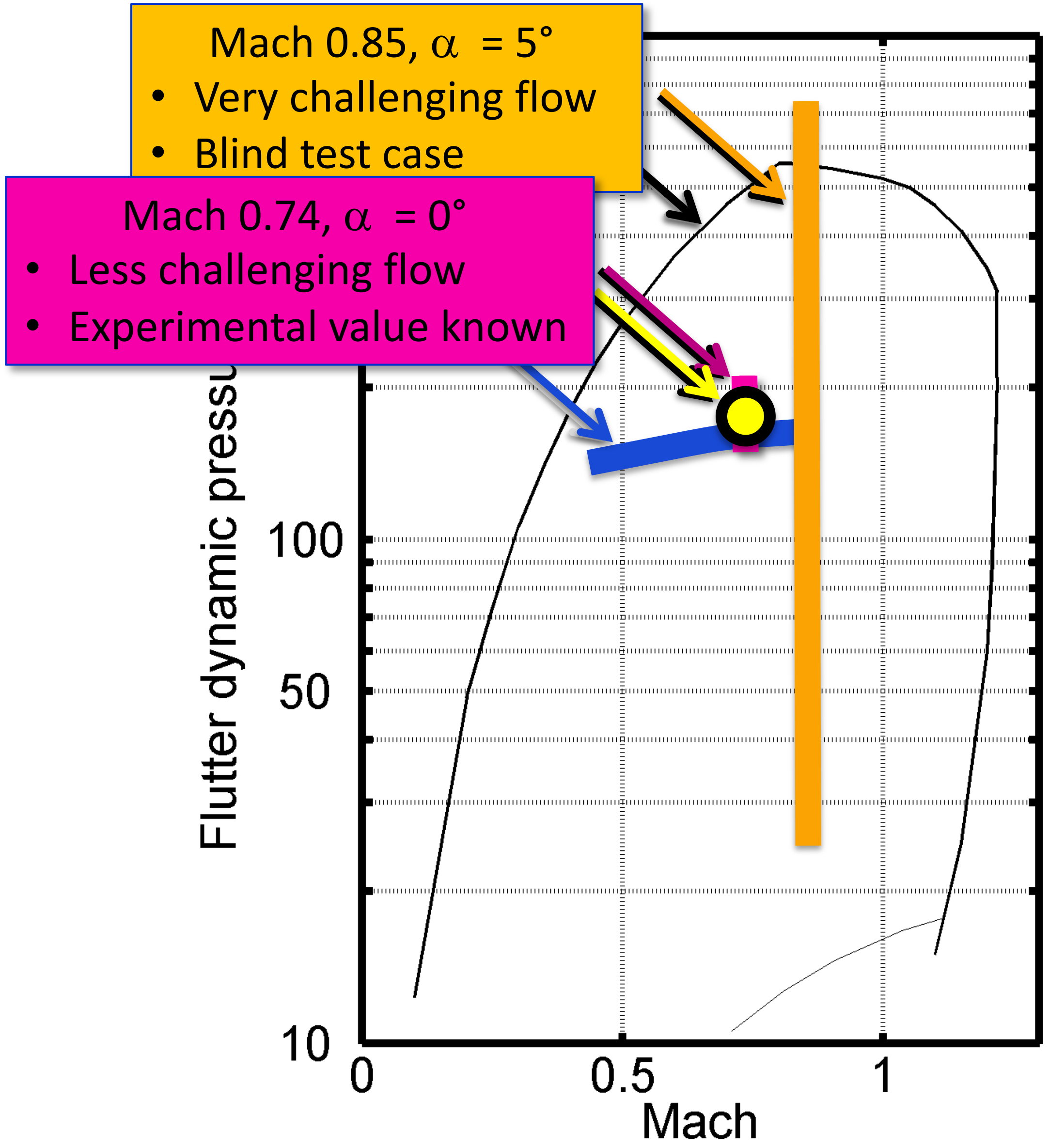
- **What have we learned regarding flow solvers?**
  - Flow solutions that offer better fidelity in capturing turbulence, such as LES or DES, have generally been recommended in the literature for analyzing cases where "massively separated flows" exist, usually occurring at high angles of attack. The highest mean angle of attack case for the AePW was the BSCW configuration, $\alpha = 5°$. This test case generated what was assessed as moderately separated flow. The workshop results for BSCW led to the assessment that the URANS solutions were insufficient for this case. Some analysts are pursuing higher order CFD methods for this configuration. In this case, at a moderate angle of attack, the separated flow features are significant enough to cause a qualitative change to the shock motion and qualitative changes in the aft loading. While these changes may or may not be significant for integrated loads such as lift and pitching moment coefficient, they are likely significant for assessing aeroelastic stability, which is highly dependent on phase relationships and load distribution.
  - In order to get the steady pressure distribution correct, it is essential to get the static aeroelastic deformed shape correct. Failure to do this results in effective changes in the angle of attack. Using the rigid shape, rather than the deflected aeroelastic shape resulted in overprediction of the pressure distribution.
  - Methodologies for analyzing unsteady oscillatory response are not standardized. Several methods were employed, although it has not been assessed whether the difference in oscillation method was a substantial source of variations observed.

- **What were the most challenging aspects regarding our chosen configurations? What were the consequences of these aspects?**
  - Each of the principal test conditions for these configurations contained an oscillating upper surface shock, and in some cases a lower surface shock. The largest magnitude of the dynamics, i.e., in the FRFs, is the shock oscillation. For forced oscillation cases, the shock oscillation follows the forcing function and responds primarily at that frequency.
  - The most challenging aspect of the RSW configuration was introduced by the proximity of the model to the wind tunnel wall and the undersized splitter plate. The consequence of attempting to capture the wall influences was that the CFD solutions varied widely, even for the unforced system results. We don't currently view the variation present in these results as an accurate assessment of the variation introduced by analysts' choice applicable to the state of the art.
  - Shock-induced separated flow and trailing edge separation was present for the BSCW configuration at our selected test conditions. Lower surface separation in the cusp region was also likely to have occurred. The computational methods that were applied had difficulty producing converged solutions for the unforced system and for the lower frequency forced oscillation case. We have attributed the convergence problems of these solutions with the complexity of the flow field.
  - HIRENASD was not as challenging as the simpler geometries of the RSW and BSCW due to test condition selection and airfoil geometry. The resulting flow physics were more easily captured by the flow solvers chosen. The zero-lift case, chosen with the thought that the shock would be less stationary, offered less of a challenge to analysts than the test case with an upper surface shock.

AePW-1 Lessons Learned:
ref. IFASD-2013-1A Heeg et al.

- **What have we learned about the state of the art in aeroelastic computations?**
  - Using RANS, we cannot accurately capture separated flow associated with the BSCW at the chosen test conditions. Although the test case was thought to contain moderately separated flow, the region of separation appears to extend from the mid-chord (shock location) to the wing trailing edge. Further, the dynamics of the flow are of essential interest in our studies. While RANS solutions may be able to predict an averaged influence of separation for small separation bubbles, they appear insufficient for either the unforced or forced oscillation responses of the BSCW configuration at Mach 0.85, α=5°.
  - Grid refinement was not shown to improve correlation with experimental data for any of the configurations. For HIRENASD, preliminary indications are that the grid refinement did, however, reduce the variation in the predictions.
  - Time step refinement was not systematically investigated by many analysts. In the few cases where it was examined and separated flow was present, qualitative changes in the results were observed.
  - Modeling inconsistencies may have been responsible for the large variations observed in both the unforced system response and the frequency response functions.

AePW-2 Flutter Results Summary



Ranges of High-Fidelity Computational Results, AePW-2

- ***Mach 0.74, 0°***
- ***Mach 0.85, 5°***

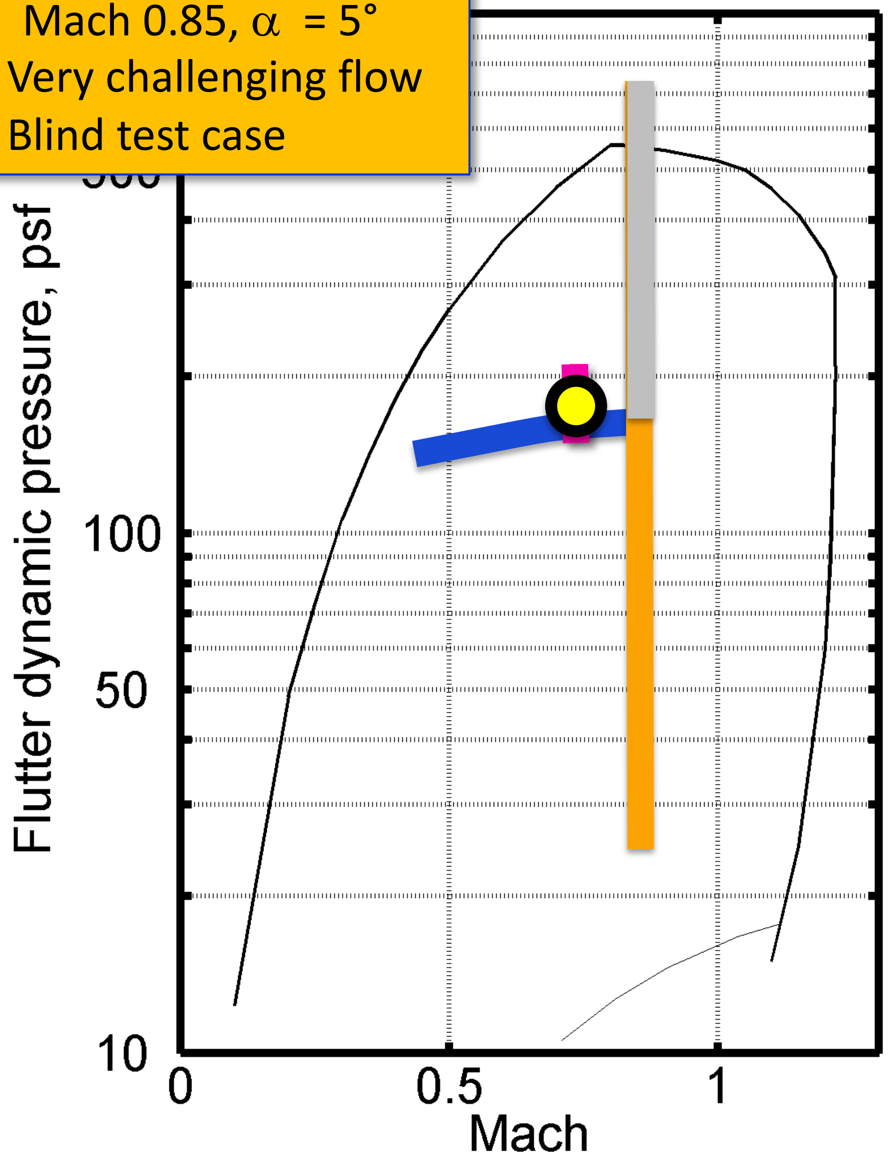
Linear Analysis Results

Experiment

Wind tunnel Operating Limits

AePW-2 Flutter Results Summary

Mach 0.85, α = 5°
- Very challenging flow
- Blind test case



Ranges of High-Fidelity Computational Results, AePW-2

Mach 0.74, 0°

Mach 0.85, 5°

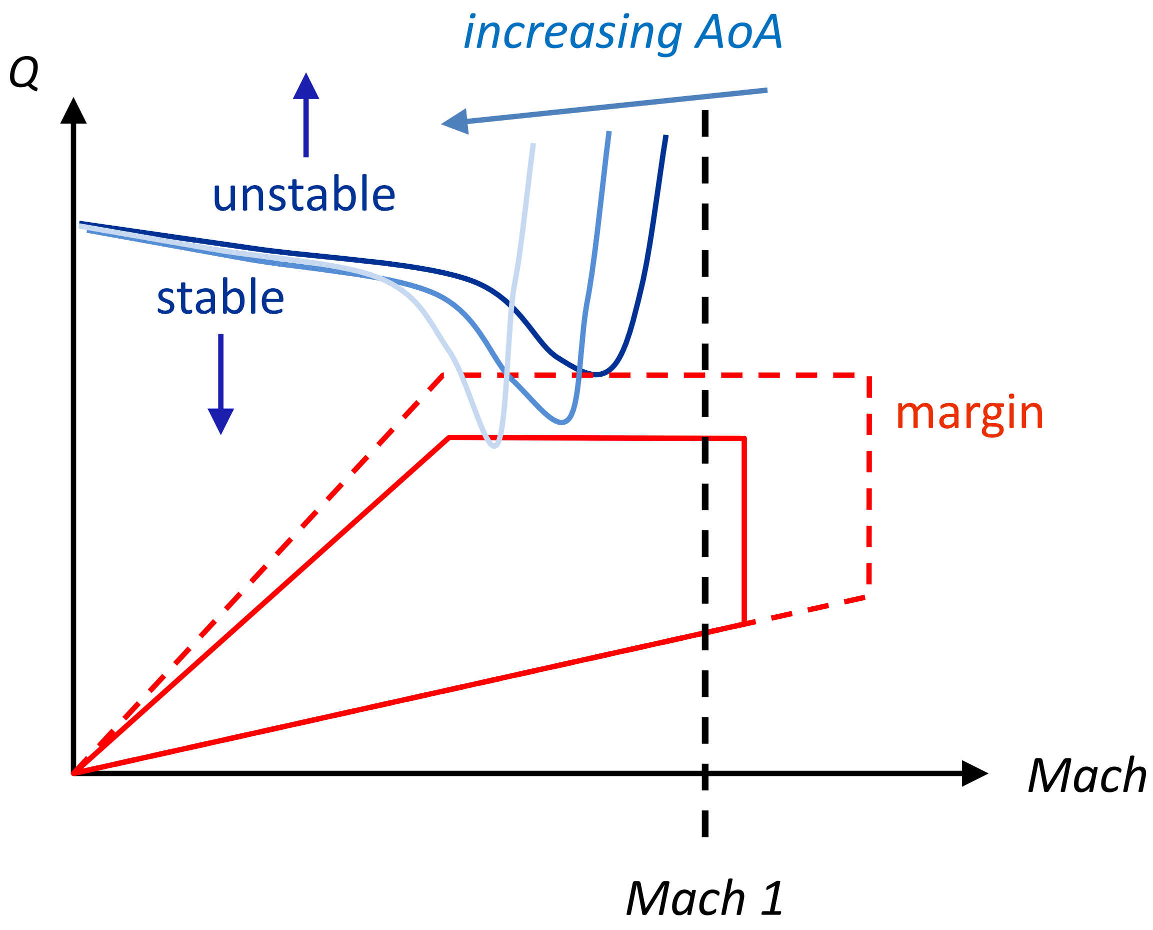
Linear Analysis Results

Experiment

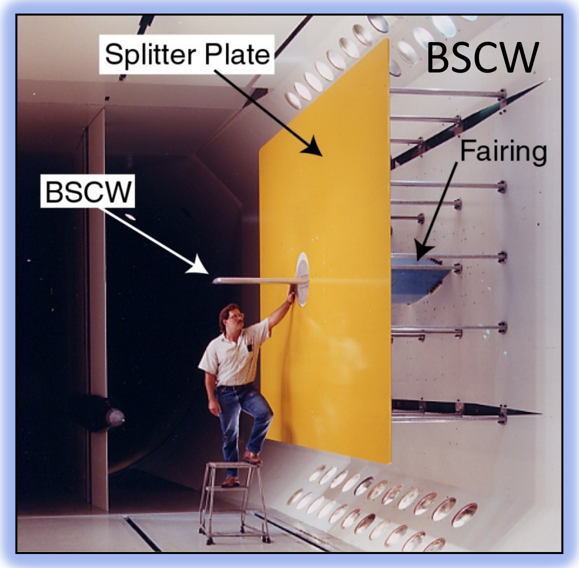
Wind tunnel Operating Limits

Post workshop analysis

Why Transonic Flutter ?



BSCW – AePW Building Block Approach



- AePW-1: Forced Oscillation in Pitch, Mach 0.85 ✓
- AePW-2:
  - Forced oscillation in pitch, Mach 0.7 ✓
  - Flutter, Mach 0.74, 0° ✓
  - Unforced Unsteady, Forced Oscillation, Flutter, Mach 0.85, 5° ✓

Mach	0.6	0.7		0.8			0.85	0.87	
q (psf) / α^0	170	100	170	100	170	200	200	100	170
-1							1.27	1.28	1.28
0							1.28	X	●
1				1.21	1.21	1.22	●	●	●
3		1.20	1.21	1.29	○	○	●	●	●
5	1.07	1.29	○	●	●	●	●	●	●

● Shock-induced separation
○ Shock-induced separation onset
X Data unavailable
Number value Sub-critical, maximum local Mach

AePW-1 case

AePW-2 case

Using local pressure coefficient & isentropic flow relationships

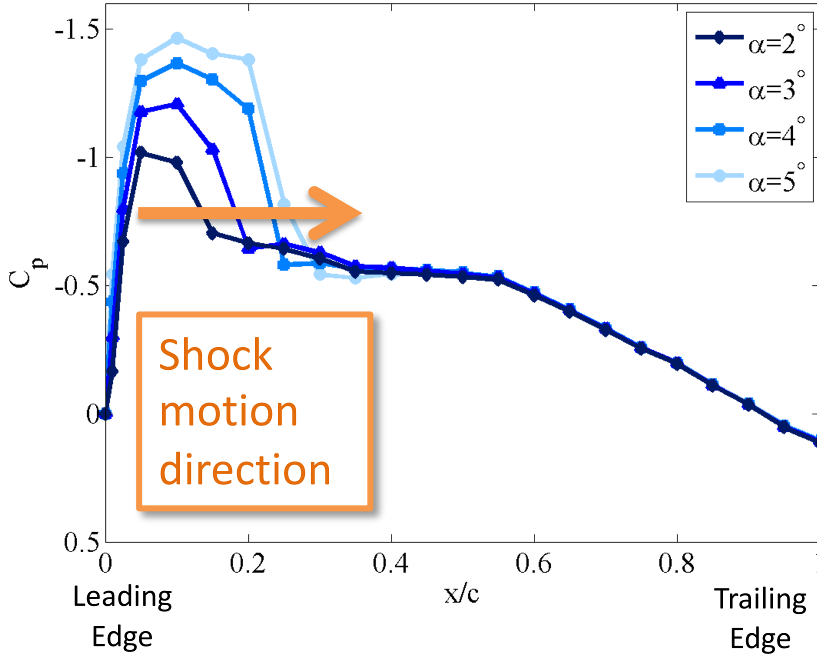
$$M_{local} = \sqrt{2/(\gamma-1)\frac{1+\frac{\gamma-1}{2}M_\infty^2}{\left(C_{p,local}\gamma M_\infty^2/2+1\right)^{\frac{\gamma-1}{\gamma}}}-1}$$

BSCW – AePW Building Block Approach

Upper surface pressure coefficient distributions at 60% span

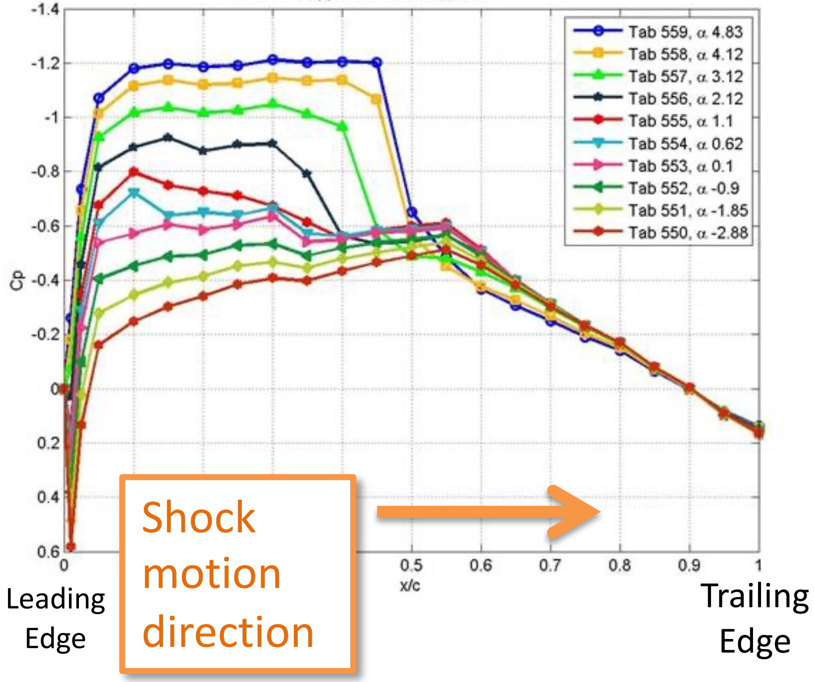
<u>Mach 0.74</u>: Attached flow

As α increases, Shock moves AFT



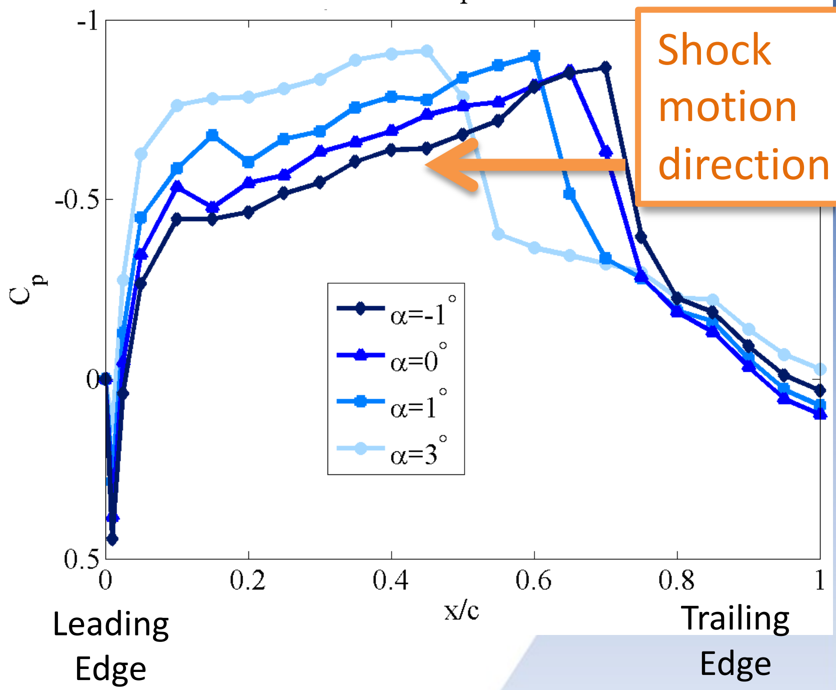
<u>Mach 0.80</u>: Attached flow

As α increases, Shock moves AFT



<u>Mach 0.88</u>: Separated flow

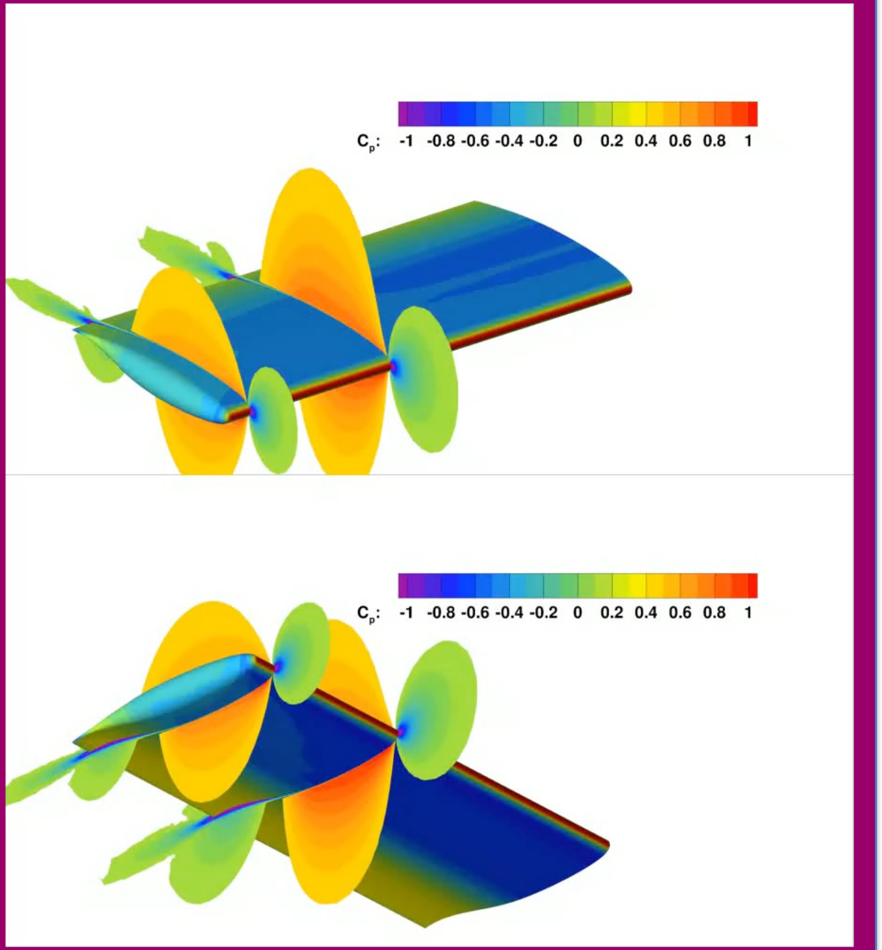
As α increases, Shock moves FORWARD



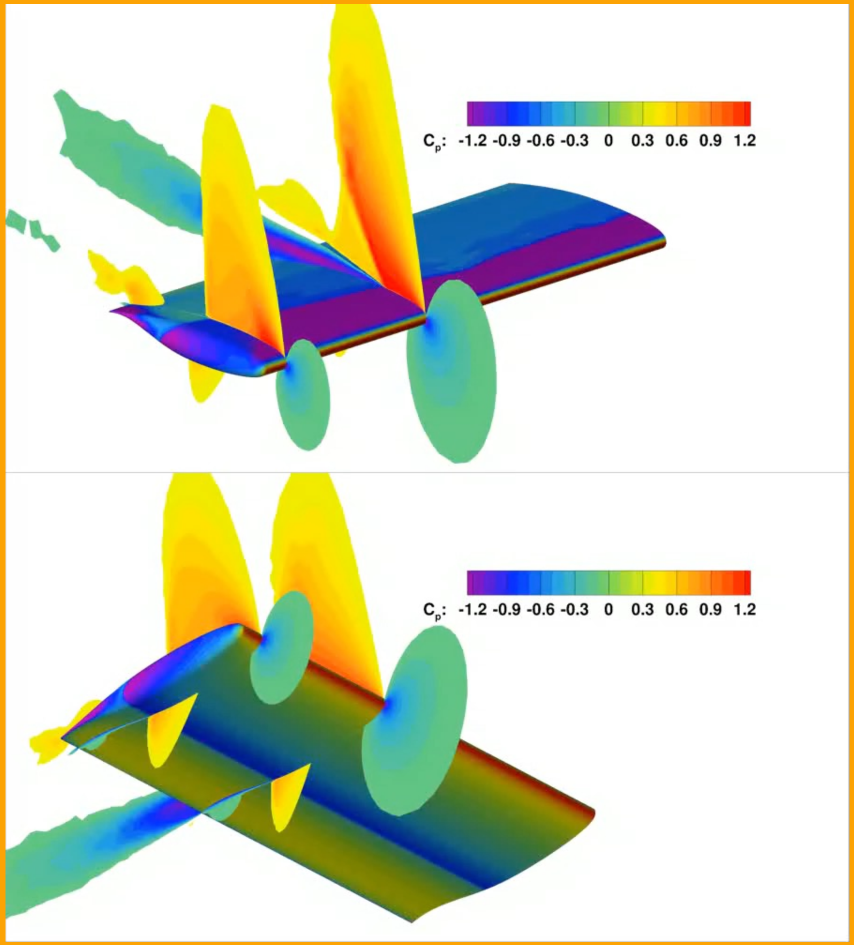
At Mach 0.80: Shows shock is strengthening and moving towards the trailing edge (<u>aft</u>) <u>as angle of attack increases</u>.

Computational Aeroelastic Simulations, FUN3D

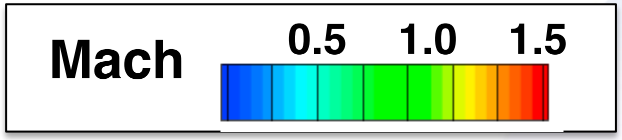
Mach 0.74, AoA = 0°



Mach 0.85, AoA = 5°

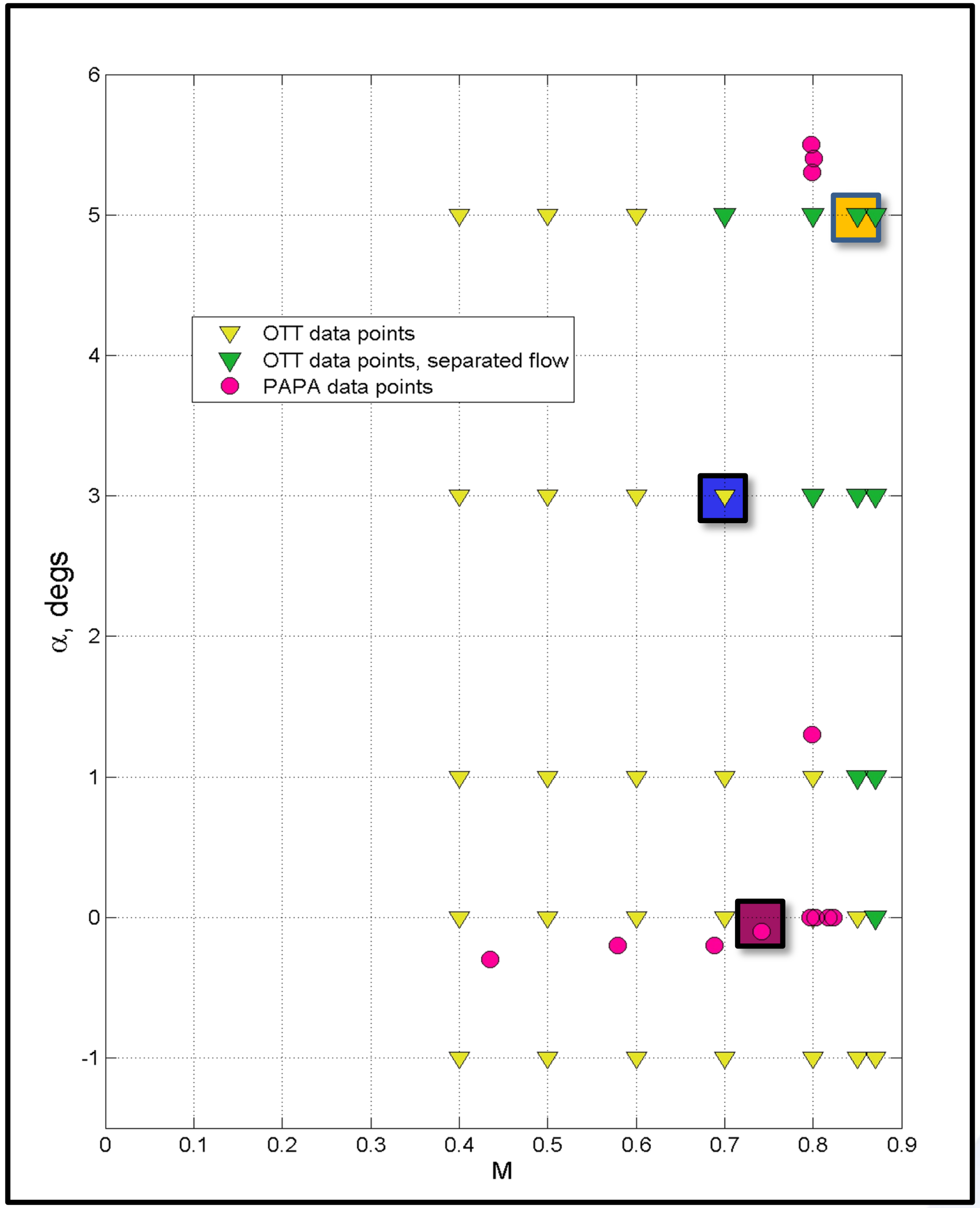


On the surfaces: colors show C_p
Off the surfaces: colors show local Mach number



BSCW – AePW Building Block Approach: Choosing AePW-3 Analysis Conditions

OTT data points
OTT data points, separated flow
PAPA data points
AePW-2 Analysis Cases



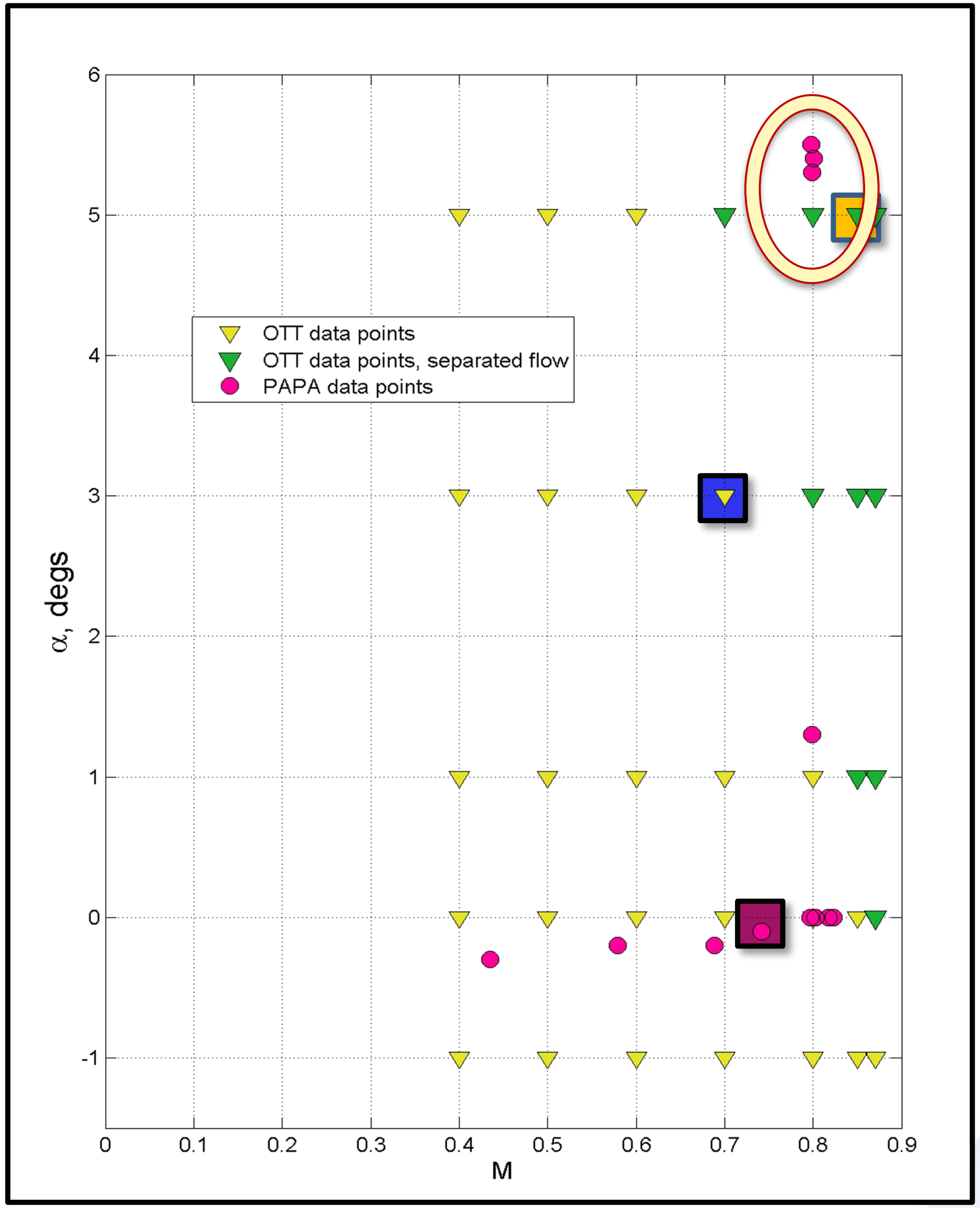
BSCW – AePW Building Block Approach: Choosing AePW-3 Analysis Conditions

▽	OTT data points
▼	OTT data points, separated flow
●	PAPA data points
■ ■ ■	**AePW-2 Analysis Cases**

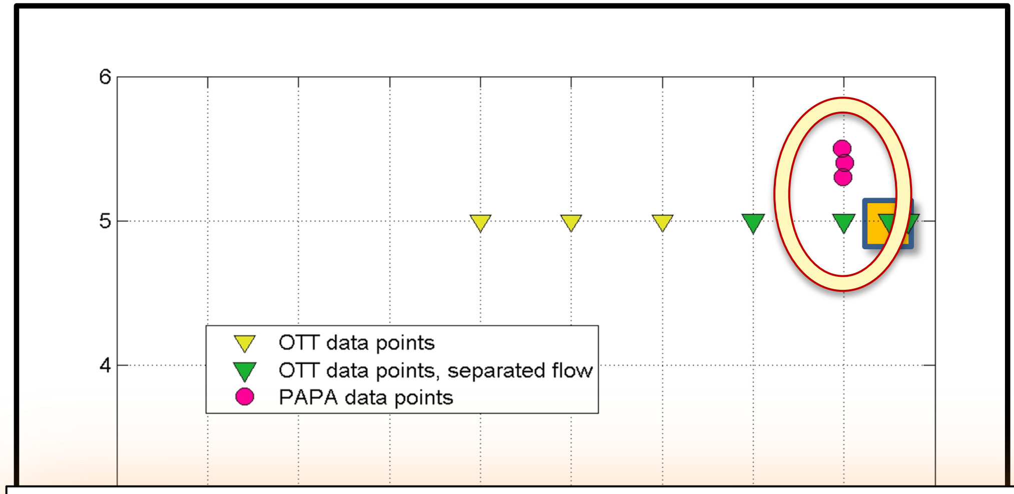
AePW-3 High Angle Working Group Analysis Conditions

Mach 0.8, AoA = 5°

Provided that new experimental will be available !!!



BSCW – AePW Building Block Approach: Choosing AePW-3 Analysis Conditions



OTT data points
OTT data points, separated flow
PAPA data points
AePW-2 Analysis Cases

AePW-3 High Angle Working Group Analysis Conditions

Mach 0.8, AoA = 5°

Provided that new experimental will be available !!!

Table 2. AePW-3 Workshop Test Cases.

	Case #1	Case #2
Mach	0.8	0.8
AoA	5°	5°
Dynamic Data Type	Flutter Unsteady	Unforced Unsteady
Notes	- Attached / Separated - PAPA exp. data - R-134a	- Shock buffet (?) - OTT exp. data - R-134a

Can we identify connection between flutter and buffet ?

Choosing AePW-3 Analysis Conditions

EXPERIMENTAL UNSTEADY PRESSURES AT FLUTTER ON THE SUPERCRITICAL WING BENCHMARK MODEL

AIAA-93-1592-CP

Bryan E. Dansberry, Michael H. Durham*, Robert M. Bennett**, José A. Rivera*, Walter A. Silva*, and Carol D. Wieseman*; Structural Dynamics Division, NASA Langley Research Center, Hampton, VA 23681-0001 and David L. Turnock*
Lockheed Engineering and Sciences Corporation

Stall Flutter: Additional flutter points were acquired at nonzero angles of attack at a constant Mach number of 0.8. These data, acquired in 11-12 with fixed transition, are presented in figure 9 as flutter dynamic pressure versus *a. The test conditions and flutter parameters for* these stall flutter points are included in table 6. Due to load limits of the PAPA mount only three points could be acquired at angles of attack greater than two degrees. The data acquired, however, shows trends consistent with those of models previously tested on the PAPA mount. Results for models previously tested on the PAPA mount show that the flutter dynamic pressure varies only slightly as *a is increased to some critical angle* (above four degrees in reference 4). At this point, a rapid decrease in flutter dynamic pressure with increasing angle of attack and a rise in the flutter frequency to very near the wind-off torsion frequency is seen. This rapid change in character from equal participation in the flutter mechanism of pitch and plunge to a pitch dominated flutter mechanism is associated with wing stall conditions during a portion of the pitch oscillation cycle.

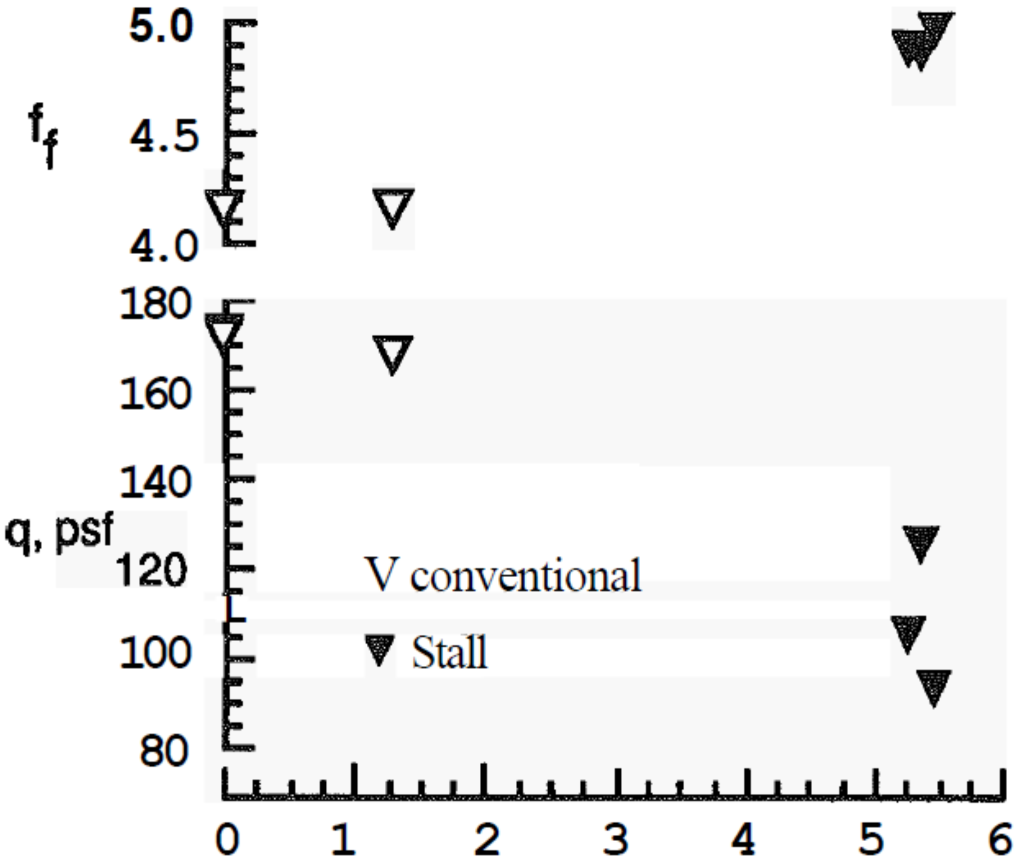


Figure 9. Stall flutter boundary in R-12 at M = 0.80.

What they have termed "stall flutter" corresponds to the test conditions where separated flow is first observed for the unforced system. For the oscillated system, the time histories from the OTT test indicate that the wing goes in and out of separated flow as the wing is pitched nose up and nose down.

Mach 0.8, AoA = 5deg Buffet and Flutter Analysis Condition

Parameter	Units													
Mach		0.799	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.801	0.801
qbar	psf	10.02	25	35	50	75	100	134	143	152	168.8	200	225	250
Mach	1/ft	0.799	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.801	0.801
qbar	psf	10.02	25	35	50	75	100	134	143	152	168.8	200	225	250
Rec		237461	592224	829213	1184801	1777732	2371336	3178880	3392751	3606668	4006103	4748658	5343835	5939368
Re	1/ft	178096	444168	621910	888601	1333299	1778502	2384160	2544563	2705001	3004577	3561493	4007876	4454526
V	ft/s	440.45	440.63	440.59	440.51	440.39	440.21	440.05	440	439.96	439.88	439.7	439.58	439.46
a	ft/s	551.08	550.94	550.85	550.71	550.48	550.25	549.94	549.86	549.78	549.62	549.34	549.11	548.88
T_static	deg_F	80.87	80.83	80.83	80.82	80.81	80.8	80.78	80.77	80.77	80.76	80.74	80.73	80.71
rho	slugs/ft3	0.000103	2.58E-04	0.000361	0.000515	0.000774	0.001032	0.001384	0.001477	0.001571	0.001745	0.002069	0.002329	0.002589
gamma		1.1121	1.1122	1.1123	1.1124	1.1126	1.1128	1.1131	1.1131	1.1132	1.1133	1.1136	1.11E+00	1.1139
mu	lb-sec/ft2	2.56E-07	2.56E-07	2.56E-07	2.56E-07	2.56E-07	2.56E-07	2.55E-07	2.55E-07	2.55E-07	2.55E-07	2.55E-07	2.55E-07	2.55E-07
Pr		0.68394	0.68404	0.6841	0.68419	0.68435	0.6845	0.68471	0.68477	0.68483	0.68493	0.68513	0.68528	0.68544
H	psf	40	99.7192	139.609	199.446	299.181	399.003	534.692	570.612	606.532	673.587	798.205	898.014	997.829
P	psf	28.2069	70.3193	98.4486	140.644	210.975	281.366	377.05	402.38	427.711	474.996	562.873	633.255	703.643
T_stagnation		100	100	100	100	100	100	100	100	100	100	100	100	100
X		0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95

High Angle Working Group Teams / Participants

Cases:

1. Flutter
2. Shock buffet

Red – Yes

Blue - Maybe

TEAM	Cases
NASA Langley, USA	1,2
Technion, Israel	1,2
USAFA, USA	1,2
BAE Systems, UK	1
UZ, Switzerland	1
IIS, India	1,2
UN, Australia	1,2
Bombardier, Canada	1
CREATE-AV, USA	1,2
Hexagon, Japan	1
Duke University, USA	1
Metacomp Tech., USA	1

What did we ask for from participating teams?

- Flutter prediction
  - Aerodynamic coefficients, CL, CD, Cm, at Q = 100 psf, steady rigid
  - Cp vs. x/c at 60% wing station at Q = 100 psf, steady rigid
  - Surface Cp and skin friction
  - Flutter Q at two or more mesh resolutions
  - Time vector, generalized displacement/velocity or plunge/pitch at ALL Qs
  - Splined mode shapes
  - Perturbation method
  - Temporal resolution study
  - Definitions: spatial / temporal schemes, flux limiter, etc.
  - Time to solution: how long does it take to obtain a flutter-point solution

What did we ask for from participating teams?

- Shock-buffet prediction
  - Time history of aerodynamic coefficients, CL, CD, Cm
  - Time history of Cp vs. x/c at 60% wing station at discrete points, five on upper surface and two on the lower surface
  - Surface Cp_RMS, surface pressure coefficients
  - PSDs, CL and Cps
  - Strouhal number
  - Temporal resolution study
  - Definitions: spatial / temporal schemes, flux limiter, etc.
  - Time to solution: how long does it take to obtain a flutter-point solution